ARROWTOOTH FLOUNDER

by
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SUMMARY

Catch and fishery length data for 2001 were updated and 2002 catch and fishery length data were added to the model. An age-based model was used with the same configuration as the 2001 assessment, except an ascending logistic selectivity curve was used for the survey instead of a smooth selectivity function. The fishery selectivities were estimated using a smooth function as in past assessment models. Natural mortality for males was set higher than for females as in previous assessments, to obtain a sex ratio of about 70% female in the population. Length composition data were fit using a fixed length-age transition matrix estimated from survey length at age data.
Survey biomass estimates from Halibut trawl surveys in the 1960's, groundfish trawl surveys in the 1970's and NMFS triennial trawl surveys from 1984 to 2001 were included in the model. The estimated biomass from the model increased from about 320,000 t in 1961 to a high of about 1,815,500 t in 2002. The 2003 ABC using F40% was 155,139 t. OFL using F35% was 181,394 t. The 2002 ABC using F40% was 146,264 t. Catch through 5 October 2002 was 19,009 t, similar to the 2001 catch of 19,964 t.

INTRODUCTION

Arrowtooth flounder (Atheresthes stomias) are currently the most abundant groundfish species in the Gulf of Alaska. Research has been conducted on their commercial utilization (Greene and Babbitt, 1990, Wasson et al., 1992, Porter et al., 1993, Reppond et al., 1993, Cullenberg 1995), however, arrowtooth flounder are currently of low value and most are discarded. In 1990, the North Pacific Fisheries Management Council separated arrowtooth flounder for management purposes from the flatfish assemblage, which at the time included all flatfish.

Although arrowtooth flounder are presently of limited economic importance as a fisheries product, trophic studies (Yang 1993, Hollowed, et al. 1995, Hollowed et al. 2000) suggest they may be an important component in understanding the dynamics of the Gulf of Alaska benthic ecosystem. The majority of the prey by weight of arrowtooth larger than 40 cm was pollock, the remainder consisting of herring, capelin, euphausids, shrimp and cephalopods (Yang 1993). The percent of pollock in the diet of arrowtooth flounder increases for sizes greater than 40 cm. Arrowtooth flounder 15 cm to 30 cm consume mostly shrimp, capelin, euphausiids and herring, with small amounts of pollock and other miscellaneous fish. Groundfish predators include Pacific cod and Halibut.

Arrowtooth flounder occur from central California to the Bering Sea, in waters from about 20m to 800m, although CPUE from survey data is highest in 100m to 300m. Information concerning stock structure is not currently available. Migration patterns are not well known for arrowtooth flounder, however, there is some indication that arrowtooth flounder move into deeper water as they grow, similar to other flatfish (Zimmerman and Goddard 1996).

CATCH HISTORY

Prior to 1990, flatfish catch in the Gulf of Alaska was reported as an aggregate of all species. The bottom trawl fishery in the Gulf of Alaska primarily targets on rock, rex and Dover sole. The best estimate of annual arrowtooth catch since 1960 was calculated by multiplying the proportion of arrowtooth in observer sampled flatfish catches in recent years (nearly 50%) by the reported flatfish catch (1960-77 from Murai et al. 1981 and 1978-93 from Wilderbuer and Brown 1993) (Table 4.1). Catch through 5 October 2002 was 19,009 t, similar to the 2001 catch of 19,964 t, however, a decrease from the 2000 catch of 24,252 t. Total allowable catch for 2002 was 8,000 t for the Western GOA, 5,000 t for the Eastern GOA, and 25,000 t for the Central GOA.

Table 4.2 documents annual research catches (1977 - 2001) from NMFS longline, trawl, and echo integration trawl surveys.

Substantial amounts of flatfish are discarded overboard in the various trawl target fisheries. The following estimates of retained and discarded catch (t) since 1991, were calculated from discard rates observed from at-sea sampling and industry reported retained catch.

Year	Discards	Retained	Percent retained
1991	2,174	19,896	10%
1992	498	22,629	2%
1993	1,488	22,565	6%
1994	458	22,011	2%
1995	2,275	16,153	12%
1996	5,438	17,093	24%
1997	2,985	13,442	18%
1998	2,057	10,943	15.80%
1999	4,265	11,943	26.30%
2000	9,938	13,044	43.20%
2001	6619	13345	33.15%
2002	10,032	10,381	49.15%

Under current fishing practices, arrowtooth flounder are mostly discarded when caught, although the percent retained has increased from below 10% in the early 1990's to 49% in 2002.

ABUNDANCE AND EXPLOITATION TRENDS

The survey biomass estimates used in this assessment are from International Pacific Halibut Commission (IPHC) trawl surveys, NMFS groundfish surveys, and NMFS triennial surveys (Table 4.3). Biomass estimates from the surveys in the 1960's and 1970's were analyzed using the same strata and methods as the triennial survey (Brown 1986). The data from the 1961 and 1962 IPHC surveys were combined to provide total coverage of the GOA area. The NMFS surveys in 1973 to 1976 were also combined to provide total coverage of the survey area. However, sample sizes were lower in the 1970's surveys (403 hauls, Table 4.3) than for other years, and some strata had less than 3 hauls. The IPHC and NMFS 1970's surveys used a 400 mesh Eastern trawl, while the triennial surveys used a noreastern trawl. The trawl used in the early surveys had no bobbin or roller gear, which would cause the gear to be more in contact with the bottom than current trawl gear. Also the locations of trawl sites may have been restricted to smooth bottoms in the earlier surveys because the trawl could not be used on rough bottoms. Selectivity of the different surveys is assumed to be equal. There is limited size composition data for the 1970's surveys but none for the 1960's surveys. Catchability (Q) was assumed to be 1.0. NMFS has conducted studies to estimate the escapement under the triennial survey net, and will estimate herding into the net from future experiments. The percent of arrowtooth flounder caught that were in the path of the net varies by size from about 40% to 50% at 20-25 cm to about 95% at greater than 40cm(Peter Munro, pers. Comm.). This results in a Q that is close to 1.0. The herding component will result in a lower population biomass than survey biomass, however is unknown at this time. The 400 mesh eastern trawl used in the 1960's and 1970's surveys was estimated to be 1.61 times as efficient at catching arrowtooth flounder than the noreastern trawl used in the NMFS triennial surveys (Brown, in prep). The 1960's and 1970's survey abundance estimates have been lowered by dividing by 1.61. A cv of 0.2 for the efficiency estimate was assumed since a variance has not been estimated at this time.

Survey abundance estimates were low in the 1960's and 1970's, increasing from about 146,000 t in 1975 to about 1,640,000 t in 1996, declining to 1,262,797 t in 1999, then increasing to about 1,622,000 t in 2001. The 2001 survey did not cover the eastern Gulf of Alaska. The average biomass estimated for the 1993 to 1999 surveys was used to estimate the biomass in the eastern Gulf for 2001 (Table 4.4). The eastern gulf biomass has been between 14% and 22% of the total biomass for the 1993-1999 surveys.

ANALYTIC APPROACH

Model Structure

The model structure is developed following Fournier and Archibald's (1982) methods, with many similarities to Methot (1990). We implemented the model using automatic differentiation software developed as a set of libraries under C++(ADModel Builder). ADModel Builder can estimate a large number of parameters in a non-linear model using automatic differentiation software extended from Greiwank and Corliss(1991) and developed into C++ class libraries. This software provides the derivative calculations needed for finding the objective function via a quasi-Newton function minimization routine(e.g., Press et al. 1992). The model implementation language (ADModel Builder) gives simple and rapid access to these routines and provides the ability to estimate the variance-covariance matrix for all parameters of interest.

Details of the population dynamics and estimation equations, description of variables and likelihood equations are presented in Appendix A (Tables A.1, A.2 and A.3) . There were a total of 124 parameters estimated in the model (Table A.4). The 22 selectivity parameters estimated in the model were constrained so that the number of effectively free parameters would be less than the total of 124. There were 40 fishing mortality deviates in the model which were constrained to be small to fit the observed catch closely. The instantaneous natural mortality rate, catchability for the survey and the Von Bertalanffy growth parameters were fixed in the model (Table A.5).

Model assumptions

Weights used on the likelihood values were 1.0 for the survey length, survey age data and the survey biomass (simply implying that the variances and sample sizes specified for each data component were approximately correct). A weight of 0.25 was used for the fishery length data. The fishery length data is essentially from bycatch and in some years has low sample sizes. A lower weight on the fishery length data allows the model to fit the survey data components better. The estimated length at age relationship is used to convert population age compositions to estimated size compositions. The current model estimated size compositions using a fixed length-age transition matrix estimated from the 1984 through 1996 survey data combined. The distribution of lengths within ages was assumed to be normal with cv's estimated from the length at age data of 0.06 for younger ages and 0.05 for older ages. Size bins were 2 cm starting at 24 cm, 3 cm bins from 40 cm to 69cm, one 5 cm bin from 70 cm to 74 cm, then a 75+cm bin. There were 13 age bins from 3 to 14 by 1 year interval, and ages over 15 accumulated in the last bin, 15+. Recruitment in the last three years (2000,2001,2002) of the model were constrained to be close to the mean recruitment over the 20 year period from 1981 to 1999, due to the lack of data to estimate recruitments for those years.

Data Sources

The model simulates the dynamics of the population and compares the expected values of the population characteristics to those observed from surveys and fishery sampling programs.

The following data sources were used in the model:

Data component	Years
Fishery catch	1960-2002
IPHC trawl survey biomass and S.E.	1961-1962
NMFS exploratory research trawl survey biomass and S.E.	1973-1976
NMFS triennial trawl survey biomass and S.E.	1984,1987,1990,1993,1996,1999,2001
Fishery size compositions	1977-1981,1984-1993,1995-2002
NMFS survey size compositions	1975,1999,2001
NMFS triennial trawl survey age composition data	1984,1987,1990,1993,1996

Sample sizes for the fishery length data were adequate for the 1970's and 1980's. However, sample sizes in recent years have decreased. No length samples were collected in 1994. Otoliths from the 1984, 1987, 1990, 1993 and 1996 triennial trawl surveys were aged in 1998 and 1999 allowing the use of age compositions in the model (Table 4.5). Size composition data for the surveys are shown in Table 4.6.

Natural mortality, Age of recruitment, and Maximum Age

The estimation of natural mortality rates for Gulf of Alaska arrowtooth flounder were analyzed using the methods of Alverson and Carney (1975), Pauly (1980), and Hoenig (1983) in the 1988 assessment (Wilderbuer and Brown 1989). The maximum age of female arrowtooth flounder otoliths collected was 23 years. Using Hoenig's empirical regression method (Hoenig 1983) M would be estimated at 0.18. There are fewer males than females in the 15+ age group, with the maximum age for males varying between 14 and 20 years from different survey years. Natural Mortality with a maximum age of 14 years and 20 years was estimated at 0.30 and 0.21 respectively using Hoenig's method.

Natural mortality was fixed at 0.2 for females. A higher natural mortality for males was used to fit the age and size composition data, which are about 70% female. A value of M=0.35 for males was chosen so that the survey selectivities for males and females both reached a maximum selectivity close to 1.0. A likelihood profile on male natural mortality resulted in a mean and mode of 0.354 with 95% confidence intervals of 0.32 to 0.38 (Figure 4.14). Model runs examining the effect of different natural mortality values for male arrowtooth flounder can be found in the Appendix of the 2000 SAFE. The prevalence of females in the survey and fishery data could be the result of lower availability for males or higher natural mortality. If lower availability is assumed, then the 3+ biomass and ABC will be higher, even though the F40% and female spawning biomass will remain unchanged. However, the data point towards a higher natural mortality rather than lower availability for males, although lower availability cannot be ruled out without further research. The age composition of males shows fewer males relative to females as fish increase in age, which would be the case for higher M for males. However, if males became unavailable to the gear at a fairly constant rate as they aged, the same effect would result. The survey and fishery data in both the Bering sea and GOA have about 70% female in the catches, which also points towards a higher M for males. Most of the abundance of arrowtooth flounder from survey data occurs at depths less than 300 meters. The fraction female is fairly constant at about 65% to 74% for depths up to 500 meters (Figure 4.15). In the deepest areas, covered in the 1999 and 1987 surveys, the fraction female was variable, being about 0.5 in 1987 and 0.83 in 1999.

The data by depth do not indicate that males in any depth strata are less available than in other depth strata.

Age at recruitment was set at three in the model due to the small number of fish caught at younger ages.

Weight at Age

The weight-length relationship for arrowtooth flounder is, $W = .003915\ L^{3.2232}$, for both sexes combined where weight is in grams and length in centimeters.

Selectivity

The shape of the selectivity curve for the fishery was constrained to be monotonically increasing with age using a smooth function (Figure 4.1). Survey selectivities were modeled using a two parameter ascending logistic function. The selectivities by age were estimated separately for females and males. The differential natural mortality and selectivities by sex resulted in a predicted fraction female of about 0.70, which is close to the fraction female in the fishery and survey length and age data.

Growth

In the growth equation shown below, L_{inf} was estimated as 101.5 cm for females and 54 cm for males(Figure 4.2). The length at age 2 (L_1) for both sexes was estimated at 20 cm and k was 0.077 for females and 0.22 for males from the survey age and length data in 1984 through 1996.

$$L_t = L_{\max} + (L_1 - L_{\max}) * \exp(-k(t-1)).$$

The mean length at age data from the surveys show no trends over time for females (Table 4.8 and Figure 4.3). Males were smaller in 1984, however other years are similar (Table 4.7 and Figure 4.4).

Maturity

Length at 50% mature was estimated at 47 cm with a logistic slope of -0.3429 from arrowtooth sampled in hauls that occurred in September from the 1993 bottom trawl survey (Zimmerman in review). Arrowtooth flounder are batch spawners, spawning from fall to winter off Washington State at depths greater than 366 m (Rickey 1995). There was some indication of migration of larger fish to deeper water in winter and shallower water in summer from examination of fisheries data off Washington, however, discarding of fish may confound observations (Rickey 1995). Length at 50% mature from survey data in 1992 off Washington was 36.8 cm for females and 28.0 cm for males, with logistic slopes of -0.54 and -0.893 respectively (Rickey 1995). Oregon arrowtooth flounder had length at 50% mature of 44 cm for females and 29 cm for males (Rickey 1995). Spawning fish were found in depths from 108m to 360m in March to August in the Gulf of Alaska (Hirshberger and Smith 1983) from analysis of trawl surveys from 1975 to 1981. Most observations of spawning fish were found in the northeastern Gulf, off Prince William Sound, off Cape St. Elias, and Icy Bay.

RESULTS

Fits to the size composition data from the fishery are shown in Figures 4.5 for females and Figure 4.6 for males. The survey length data in 1975 were fit well by the model, however, the length data from the 1999 and 2001 surveys lacked larger female fish that are estimated by the model (Figures 4.7 and 4.8). The high recruitments in the 1980's and early 1990's and the low fishing mortalities resulted in more large older female fish in the estimated population than were found in the 1999 and 2001 surveys. The survey length data for males is fit well (Figure 4.8). The survey age data in 1993 and 1996 indicate some accumulation of older female fish in the 15+ age bin, which is slightly overestimated by the model (Figure 4.9).

Model estimates of biomass

The model estimates of age 3+ biomass increased from a low of about 320,000 t in 1961 to a high of about 1,815,500 t in 2002 (Table 4.9 and Figure 4.11). The 2001 survey biomass estimate was 1,621,890 t, an increase from the 1999 survey biomass estimate of 1,262,797 t.

Model estimates of recruitment

The model estimates of age 3 recruits increase in the 1970's and 1980's then decrease in the 1990's (Table 4.9 and Figure 4.12). Recruitment in 2000 to 2002 was constrained to be close to the historical harmonic mean recruitment for 1981 to 1999. This was done as a precautionary approach since the harmonic mean recruitment is less than the arithmetic mean recruitment.

Spawner-Recruit Relationship

No spawner-recruit curve was used in the Model. Recruitments were estimated as deviations from a mean value on a log scale.

REFERENCE FISHING MORTALITY RATES AND YIELDS

Reliable estimates of biomass, $B_{35\%}$, $F_{35\%}$ and $F_{40\%}$, are available, and current biomass is greater than $B_{40\%}$. Therefore, arrowtooth flounder is in tier 3a of the ABC and overfishing definitions. Under this definition, $F_{ofl}= F_{35\%}$, and F_{ABC} is less than or equal to $F_{40\%}$.

Yield for 2003 using $F_{40\%} = 0.14$ was estimated at 155,139 t. Yield at $F_{35\%} = 0.165$ was estimated at 181,394 t. The fishing mortality rates for 2003 are slightly higher than in the 2002 assessment ($F_{40\%} = 0.134$, $F_{35\%} = 0.159$) due to changes in fishery selectivities. Survey selectivities were estimated using a two parameter logistic function rather than a smooth function in the 2002 assessment, which resulted in a small change in the fishery selectivities.

MAXIMUM SUSTAINABLE YIELD

Since there is no estimate of the spawner-recruit relationship for arrowtooth flounder, no attempt has been made to estimate MSY. However, using the projection model described in the next section, spawning biomass with F=0 was estimated at 1,236,240 t. $B_{35\%}$ (equilibrium spawning biomass with fishing at $F_{35\%}$) is estimated at 432,683 t.

PROJECTED CATCH AND ABUNDANCE

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Protection Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2002 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2003 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2002. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2003, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

> *Scenario 1*: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)
>
> *Scenario 2*: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2003 recommended in the assessment to the *max* F_{ABC} for 2003. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)
>
> *Scenario 3*: In all future years, F is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)
>
> *Scenario 4*: In all future years, F is set equal to the 1995-1999 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)
>
> *Scenario 5*: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above ½ of its MSY level in 2003 and above its MSY level in 2013 under this scenario, then the stock is not overfished.)

Scenario 7: In 2003 and 2004, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2015 under this scenario, then the stock is not approaching an overfished condition.)

Projected catch and abundance were estimated using $F_{40\%}$, F equal to the average F from 1995 to 1999, F equal to one half $F_{40\%}$, and F=0 from 2003 to 2007 (Table 4.10). Under scenario 6 above, the year 2003 female spawning biomass is 1,117,490 t and the year 2013 spawning biomass is 477,180 t, above the $B_{35\%}$ level of 432,683 t. For scenario 7 above, the year 2015 spawning biomass is 462,795 t also above $B_{35\%}$.

ACCEPTABLE BIOLOGICAL CATCH

ABC for 2003 using $F_{40\%}$ = 0.14 was estimated at 155,139 t. In last year's assessment ABC for 2002 using $F_{40\%}$ = 0.134 was estimated at 146,264 t (Turnock, Wilderbuer and Brown 2000).
The ABC by management area using $F_{40\%}$ was estimated by calculating the fraction of the 2001 survey biomass in each area and applying that fraction to the ABC:

Arrowtooth ABC by INPFC area

	Western	Central	West Yakutat	East Yakutat/SE	Total
ABC 2003	17,992	113,047	18,194	5,906	155,139

OVERFISHING DEFINITION

Yield at $F_{35\%}$ = 0.165 was estimated at 181,394 t.

SUMMARY

Table 4.11 shows a summary of model results.

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Table 4.1. Catch of arrowtooth flounder in the Gulf of Alaska from 1964 to 5 October, 2002.

Year	Catch(mt)
1964	514
1965	514
1966	2,469
1967	2,276
1968	1,697
1969	1,315
1970	1,886
1971	1,185
1972	4,477
1973	10,007
1974	4,883
1975	2,776
1976	3,045
1977	9,449
1978	8,409
1979	7,579
1980	7,848
1981	7,433
1982	4,639
1983	6,331
1984	3,457
1985	1,539
1986	1,221
1987	4,963
1988	5,138
1989	2,584
1990	7,706
1991	10,034
1992	15,970
1993	15,559
1994	23,560
1995	18,428
1996	22,583
1997	16,319
1998	12,975
1999	16,207
2000	24,252
2001	19,964
2002	19,009

Table 4.2. Catches from NMFS research cruises from 1977 to 2002.

Year	Catch (mt)
1977	29.3
1978	30.6
1979	38.9
1980	36.7
1981	151.5
1982	90.2
1983	61.4
1984	223.9
1985	149.4
1986	179.0
1987	297.4
1988	22.0
1989	64.1
1990	228.1
1991	27.7
1992	32.1
1993	255.4
1994	36.7
1995	173.5
1996	154.6
1997	40.6
1998	115.6
1999	101.5
2000	24.0
2001	83.9
2002	11.0

Table 4.3. Biomass estimates and standard errors from bottom trawl surveys.

Survey	Biomass(mt)	s.e.	Hauls
IPHC 1961-1962	283,799	61,515	1,172
NMFS groundfish 1973-1976	145,744	33,531	403
NMFS triennial 1984	979,335	71,209	930
NMFS triennial 1987	979,957	74,673	783
NMFS triennial 1990	1,922,107	239,150	708
NMFS triennial 1993	1,585,040	101,160	776
NMFS triennial 1996	1,639,671	114,792	804
NMFS triennial 1999	1,262,797	99,329	764
NMFS triennial 2001	1,621,892	178,408	489

Table 4.4. Survey biomass estimates (mt) for 1993 to 2001 by area. The 2001 survey biomass for the eastern gulf was estimated by using the average of the 1993 to 1999 biomass estimates in the eastern gulf.

Area	1993	1996	1999	2001
Western	212,332	202,594	143,374	188,100
Central	1,117,361	1,176,714	845,176	1,181,848
Eastern	222,015	260,324	273,490	251,943*

Table 4.5. Age data from triennial surveys in 1984 through 1996. The numbers are percentages, where the female plus the male numbers add to 100 within a year.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
females																							
1984	0.01	0.00	3.61	5.87	10.37	15.82	8.55	5.41	2.30	1.65	1.17	1.25	0.70	0.83	2.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1987	0.00	1.93	7.86	9.18	7.05	8.00	5.23	11.81	6.98	3.37	0.91	0.98	1.69	0.27	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1990	0.00	2.81	5.48	6.50	11.40	11.07	6.52	7.34	4.38	2.41	3.77	2.29	1.28	0.74	0.84	0.64	0.96	0.61	0.21	0.00	0.16	0.00	0.00
1993	0.13	4.40	6.54	6.03	6.44	7.65	8.12	7.88	9.60	4.60	2.54	2.77	1.63	1.05	0.46	0.23	0.33	0.13	0.02	0.02	0.02	0.00	0.01
1996	0.03	3.93	5.71	6.76	6.83	8.74	8.79	7.17	7.84	8.35	2.27	1.28	0.89	0.55	0.14	0.14	0.00	0.01	0.00	0.01	0.00	0.00	0.00
males																							
1984	0.00	0.00	0.56	4.42	5.31	4.05	5.10	5.44	3.76	2.72	2.46	1.66	1.05	0.88	2.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1987	0.00	0.00	8.10	6.95	8.08	3.62	2.40	2.44	0.45	0.00	0.69	1.03	0.35	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1990	0.00	2.51	3.53	4.90	5.10	4.42	4.54	0.67	2.33	1.27	1.24	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1993	0.08	2.90	3.75	2.53	2.70	6.70	3.20	2.63	1.93	1.08	0.77	0.45	0.24	0.12	0.09	0.11	0.00	0.04	0.00	0.09	0.00	0.00	0.00
1996	0.07	2.64	3.47	3.54	3.70	5.82	2.88	4.04	1.48	1.09	1.06	0.50	0.12	0.05	0.05	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00

6

Table 4.6. Length data from triennial surveys in 1984 through 2001. The numbers are percentages, where the female plus the male numbers add to 100 within a year.

Length(cm)

	22	24	26	28	30	32	34	36	38	40	43	46	49	52	55	58	61	64	67	70	75+
Female																					
1975	4.99	4.38	4.77	5.07	4.59	4.58	4.83	4.89	4.05	4.02	3.21	2.79	2.37	1.49	1.04	0.67	0.38	0.34	0.21	0.14	0.01
1999	1.90	1.78	2.89	3.34	3.18	3.35	3.68	3.56	3.25	4.30	3.98	4.81	5.92	7.46	7.26	4.11	1.84	1.06	0.69	0.53	0.33
2001	4.10	2.51	2.00	2.66	3.21	2.89	3.04	3.47	3.29	5.06	5.53	5.99	6.14	5.63	5.76	4.18	2.32	1.39	1.00	1.29	0.36
Male																					
1975	3.63	3.19	3.91	4.72	4.69	4.64	4.68	3.96	2.88	2.35	0.91	0.16	0.04	0.03	0.02	0.01	0.01	0.00	0.00	0.00	0.00
1999	1.22	1.14	1.83	1.98	1.93	1.91	2.00	1.95	2.04	3.31	4.34	3.76	1.76	0.24	0.05	0.03	0.00	0.00	0.00	0.00	0.00
2001	2.46	1.36	1.55	2.00	1.87	1.82	1.87	1.88	1.84	3.31	3.27	3.02	1.62	0.28	0.01	0.00	0.00	0.00	0.00	0.00	0.00

Table 4.7. Mean length (cm) at age for male arrowtooth flounder from triennial surveys 1984 through 1996.

	1984	1987	1990	1993	1996
1	0.0	0.0	0.0	15.8	14.5
2	0.0	23.8	0.0	21.4	20.7
3	22.3	28.4	28.6	27.6	26.3
4	26.0	33.1	33.6	31.9	34.0
5	29.9	36.9	37.2	36.9	35.3
6	33.6	41.1	39.4	40.9	41.1
7	36.1	41.2	41.8	42.2	43.6
8	37.8	42.5	43.7	44.3	44.7
9	39.3	42.8	44.5	45.7	46.9
10	40.1	0.0	45.3	45.5	46.9
11	41.7	42.5	46.2	46.2	48.1
12	42.6	42.9	0.0	48.8	49.1
13	42.9	45.0	0.0	47.1	49.3
14	44.3	45.0	51.0	40.0	51.0
15	47.5	0.0	0.0	48.0	52.0
16	0.0	0.0	0.0	47.0	0.0
17	0.0	0.0	0.0	0.0	51.0
18	0.0	0.0	0.0	52.0	0.0
19	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	48.0	0.0

Table 4.8. Mean length (cm) at age for female arrowtooth flounder from triennial surveys 1984 through 1996.

	1984	1987	1990	1993	1996
1	0.0	0.0	0.0	15.4	13.3
2	0.0	23.0	22.6	21.5	21.5
3	25.2	30.1	27.9	27.6	26.3
4	31.5	35.3	33.2	32.5	32.9
5	38.0	38.6	38.1	39.4	37.4
6	42.3	44.9	43.5	41.7	42.1
7	46.6	47.2	45.4	46.5	46.6
8	50.8	50.1	49.1	48.5	49.7
9	54.0	51.7	51.7	52.5	53.6
10	56.7	50.4	55.8	55.6	54.8
11	58.9	50.2	58.3	55.8	59.2
12	60.8	51.5	58.3	55.9	63.8
13	62.8	55.2	58.5	61.5	64.7
14	63.9	51.0	63.8	59.7	68.2
15	66.8	57.0	56.2	60.5	73.7
16	0.0	0.0	60.8	67.2	68.3
17	0.0	0.0	74.7	64.4	0.0
18	0.0	0.0	73.4	69.1	81.0
19	0.0	0.0	63.0	76.7	0.0
20	0.0	0.0	0.0	70.6	82.0
21	0.0	0.0	70.0	81.2	0.0
22	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	79.0	0.0

Table 4.9. Estimated age 3+ population biomass(mt), female spawning biomass(mt) and age 3 recruits(1,000's).

Year	age 3+ biomass	Female spawning biomass	Age 3 recruits (1,000's)
1961	320,430	192,084	84,929
1962	329,685	201,629	80,225
1963	334,933	208,437	74,080
1964	338,075	213,321	76,820
1965	339,021	216,757	73,584
1966	339,190	218,895	77,125
1967	336,665	217,942	78,527
1968	334,820	216,079	83,391
1969	335,126	214,187	91,924
1970	338,681	212,540	105,873
1971	344,217	210,696	114,831
1972	360,139	210,139	169,084
1973	387,843	207,871	247,536
1974	432,923	202,924	359,809
1975	506,036	205,019	447,182
1976	565,363	214,667	272,245
1977	633,702	233,659	344,148
1978	688,553	262,433	293,300
1979	736,014	305,853	255,856
1980	783,348	356,831	281,153
1981	845,490	405,754	401,105
1982	912,398	450,883	413,667
1983	961,337	492,687	270,404
1984	1,008,970	531,617	301,459
1985	1,075,980	576,593	420,707
1986	1,157,650	630,560	473,929
1987	1,252,230	683,750	545,052
1988	1,314,410	710,355	461,180
1989	1,376,160	740,780	440,126
1990	1,438,820	774,727	491,499
1991	1,481,630	810,679	426,173
1992	1,526,870	851,778	472,713
1993	1,600,280	893,845	659,540
1994	1,655,710	929,400	519,369
1995	1,678,000	943,691	459,045
1996	1,703,760	965,572	452,248
1997	1,725,450	996,554	431,820
1998	1,760,080	1,037,870	505,407
1999	1,794,340	1,079,200	482,760
2000	1,808,480	1,099,790	456,082
2001	1,810,040	1,104,870	463,181
2002	1,815,540	1,113,830	449,072

Table 4.10. Projected female spawning biomass and yield from 2003 to 2007.

Year	Female spawning biomass(mt)	Yield(mt)
F=F40%		
2003	1,117,490	155,139
2004	1,011,010	141,330
2005	925,059	130,323
2006	839,233	119,832
2007	763,637	110,883
F=0.011(avg F)		
2003	1,117,490	12,820
2004	1,129,640	12,925
2005	1,150,120	13,095
2006	1,153,600	13,107
2007	1,151,110	13,066
F=0.5 F40%		
2003	1,117,490	79,719
2004	1,073,650	76,717
2005	1,040,870	74,416
2006	996,854	71,584
2007	953,074	68,875
F=0		
2003	1,117,490	0
2004	1,140,400	0
2005	1,171,750	0
2006	1,185,530	0
2007	1,192,580	0

Table 4.11. Summary of results of arrowtooth flounder assessment in the Gulf of Alaska.

Natural Mortality		0.2 females 0.35 males
Age of full(95%) selection		9 females, 12 males
Reference fishing mortalities		
	$F_{40\%}$	0.140
	$F_{35\%}$	0.165
Biomass at MSY		N/A
Equilibrium unfished Spawning biomass		1,236,240 t
$B_{35\%}$ Spawning biomass fishing at $F_{35\%}$		432,683 t
$B_{40\%}$ Spawning biomass fishing at $F_{40\%}$		494,495 t
Projected 2003 biomass		
	Total(age 3+)	1,813,980 t
	Spawning	1,117,490 t
	Exploitable	1,302,000 t
Overfishing level for 2003		181,394 t

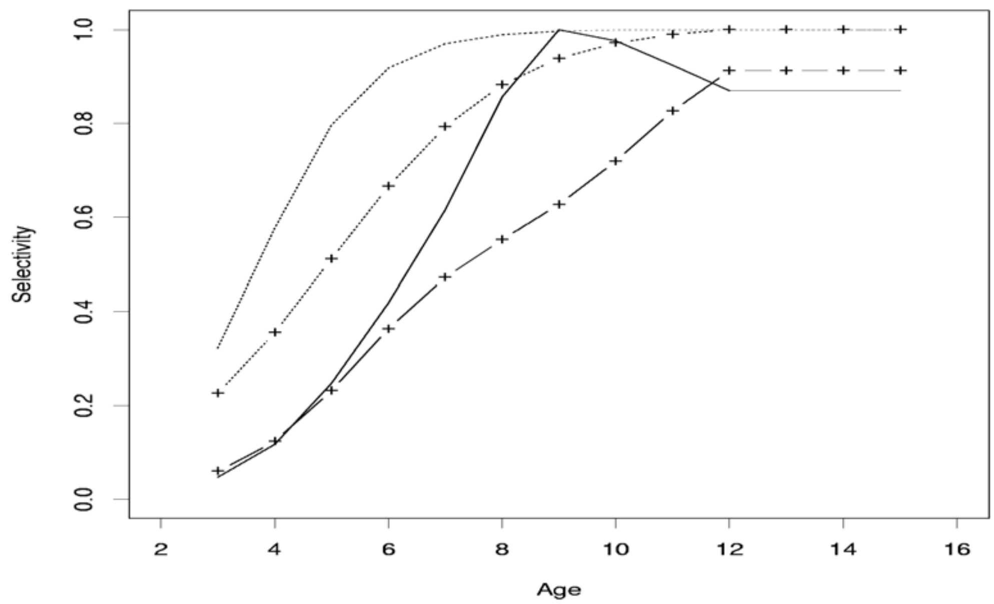

Figure 4.1. Selectivities for the fishery (solid line) and survey (dotted line). Males are the lines with the + symbol.

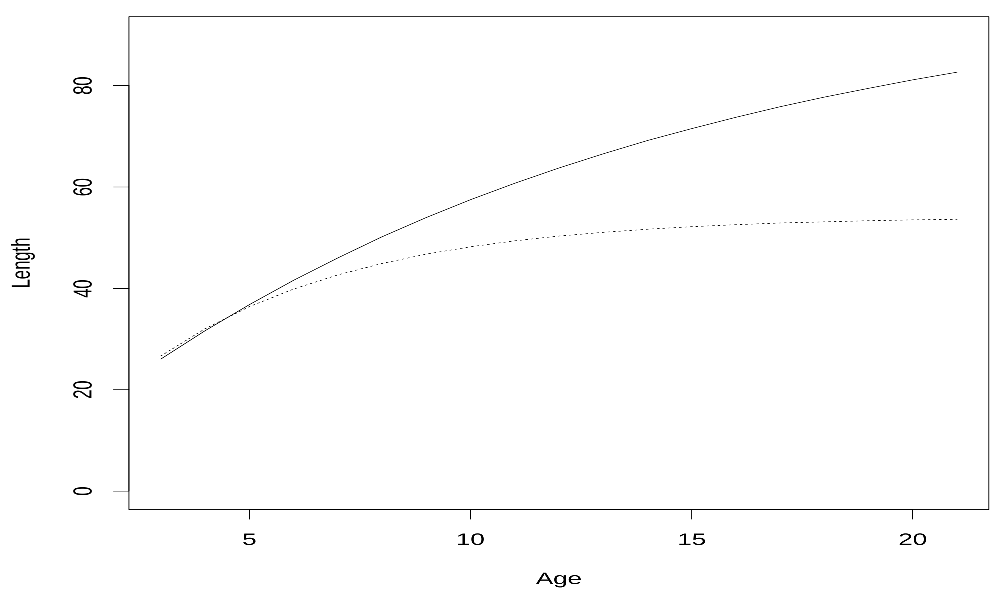

Figure 4.2. Mean length at age estimated from the 1984 through 1996 survey combined(females solid line, males dotted line), used to estimate the length-age transition matrix.

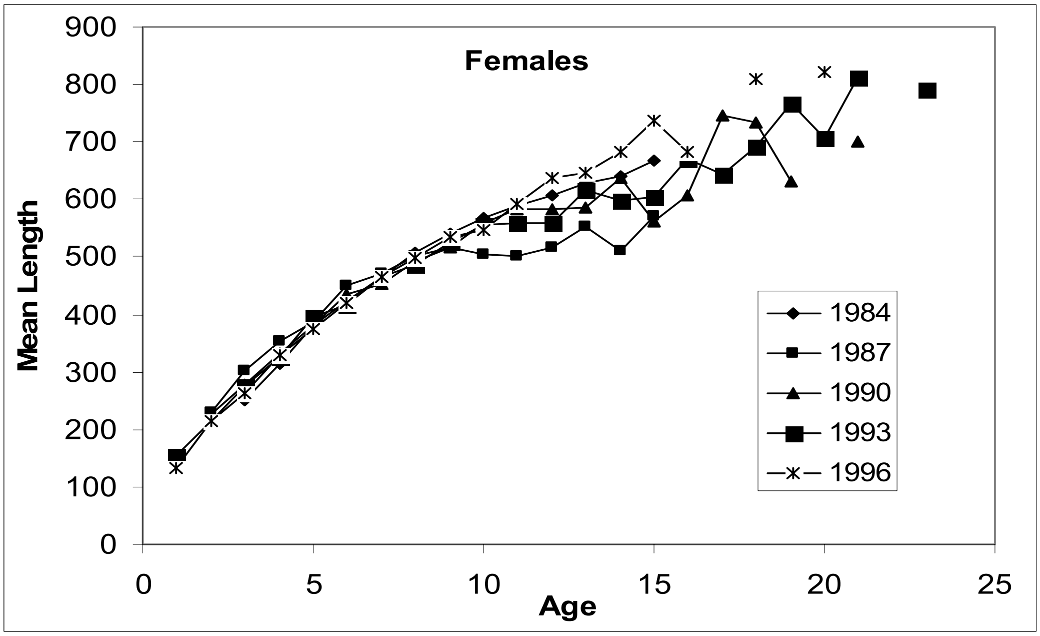

Figure 4.3. Mean length at age for female arrowtooth flounder from survey data 1984 to 1996.

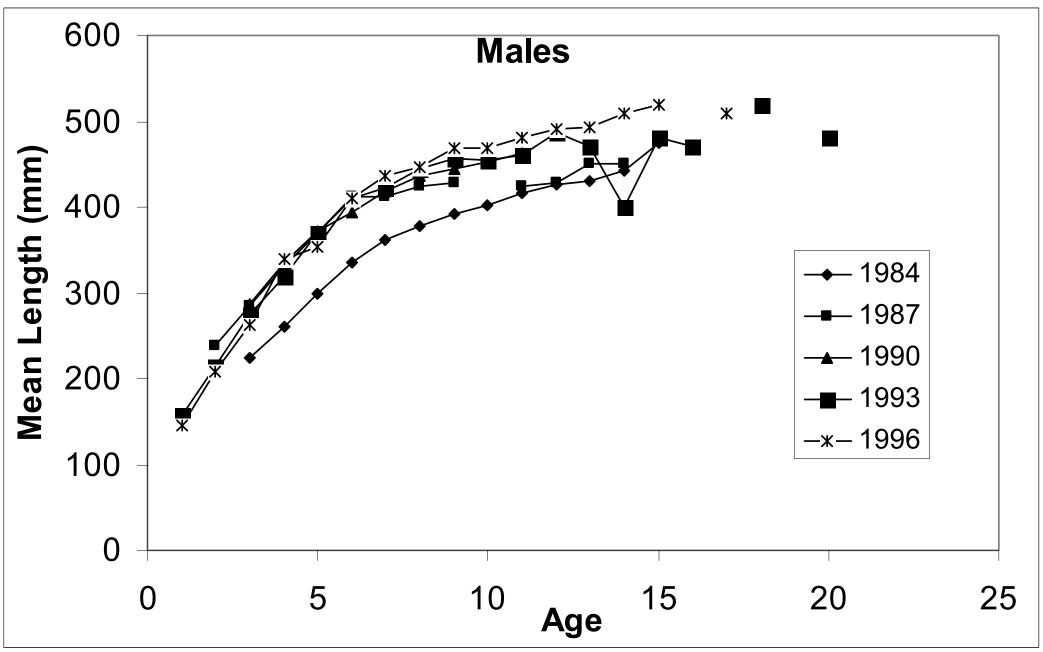

Figure 4.4. Mean length at age for male arrowtooth flounder from survey data 1984 to 1996.

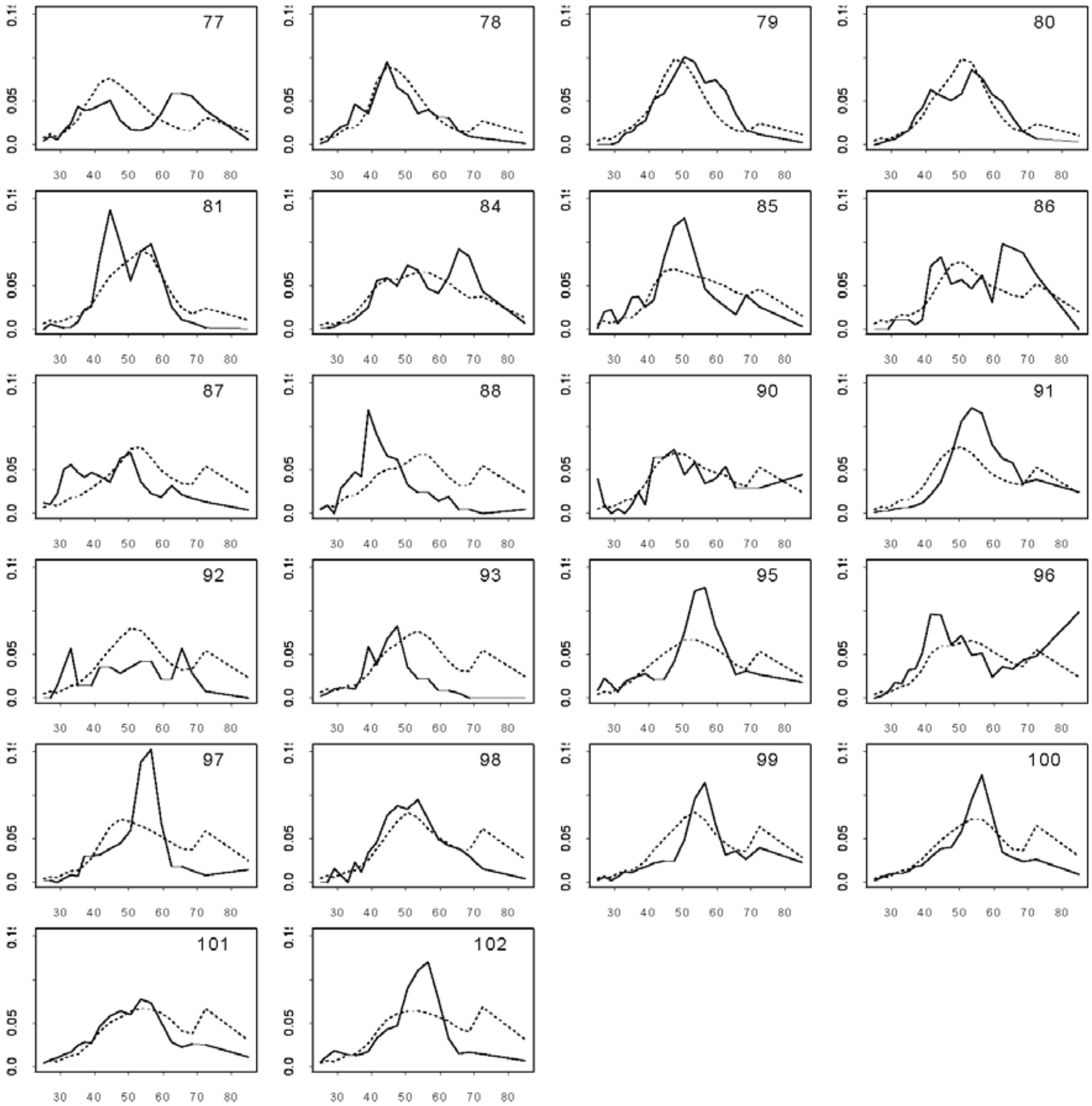

Figure 4.5. Fit to the female fishery length composition data. Dotted line is predicted. 100-102 are years 2000-2002.

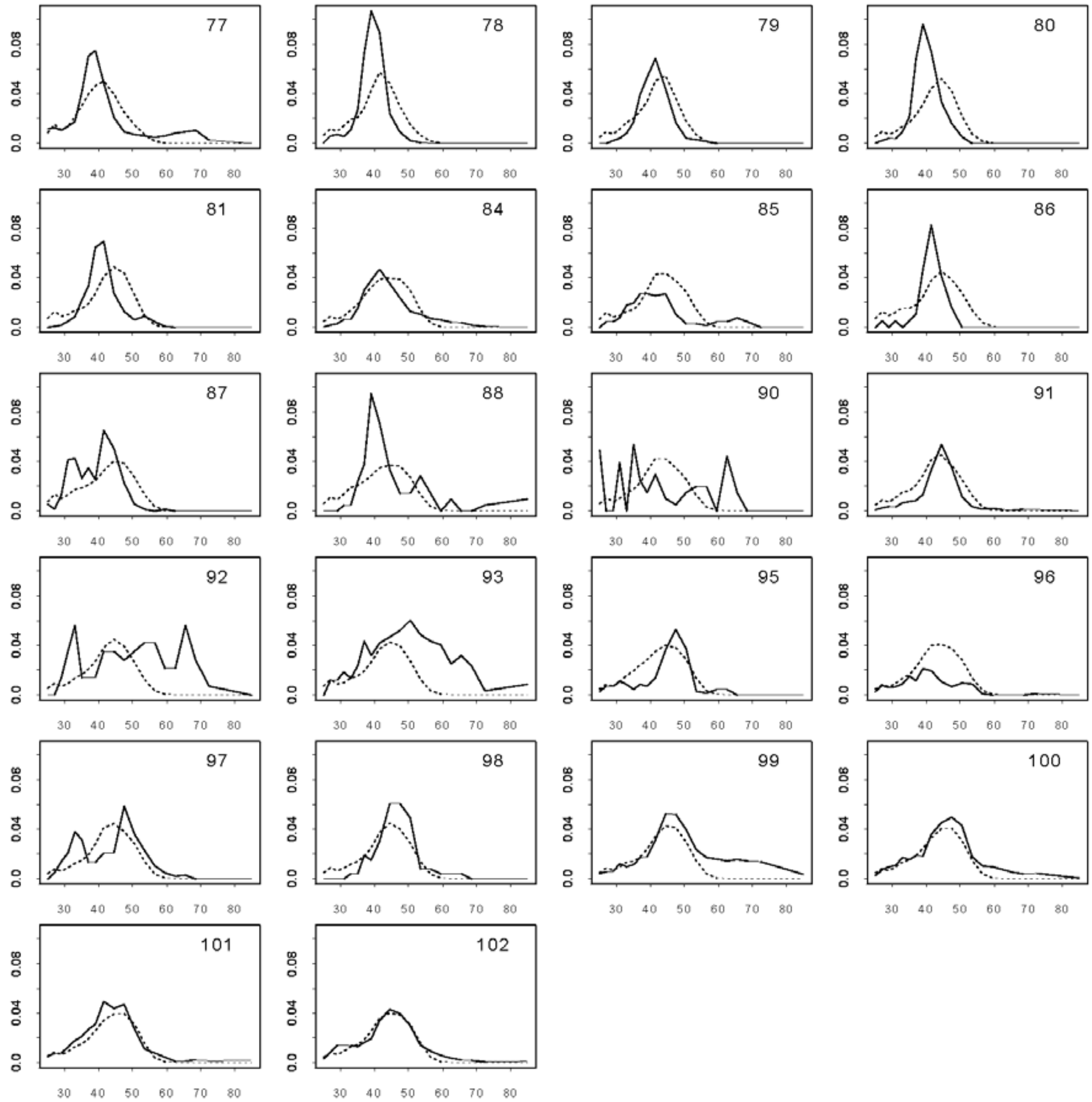

Figure 4.6. Fit to the male fishery length composition data. Dotted line is predicted. 100-102 are years 2000-2002.

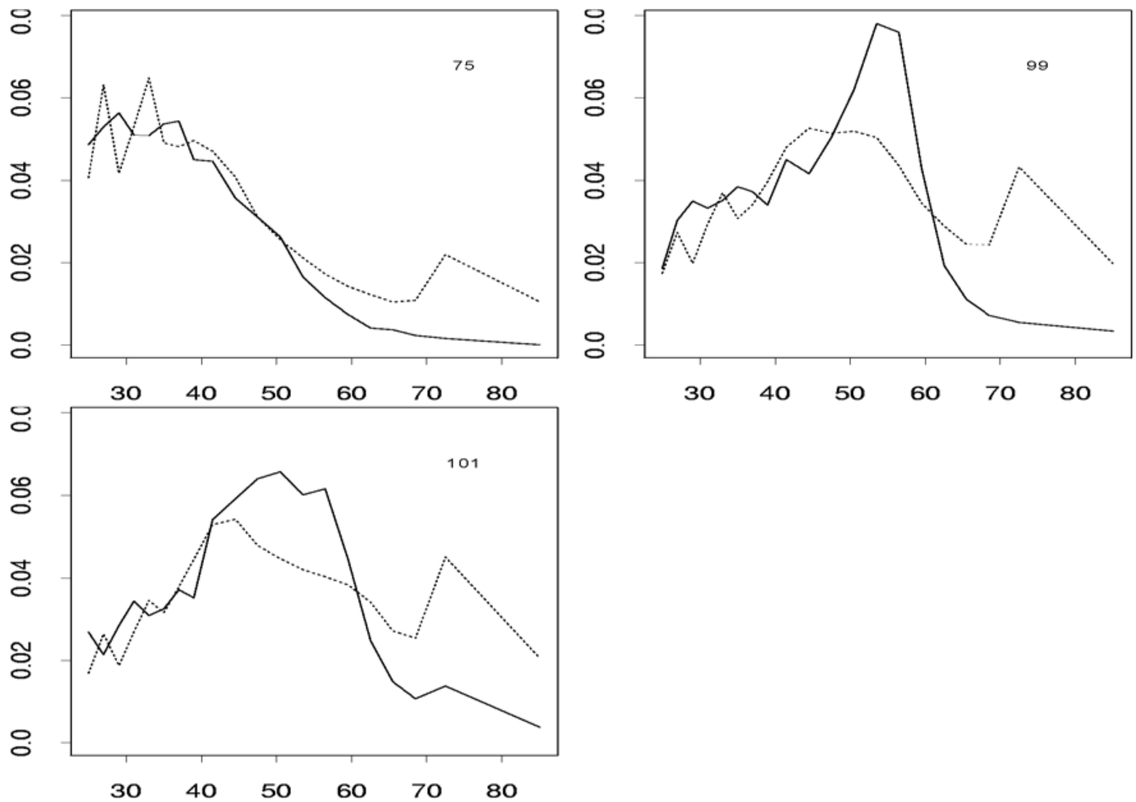

Figure 4.7. Fit to the female survey length data. Dotted line is predicted. 101 is year 2001.

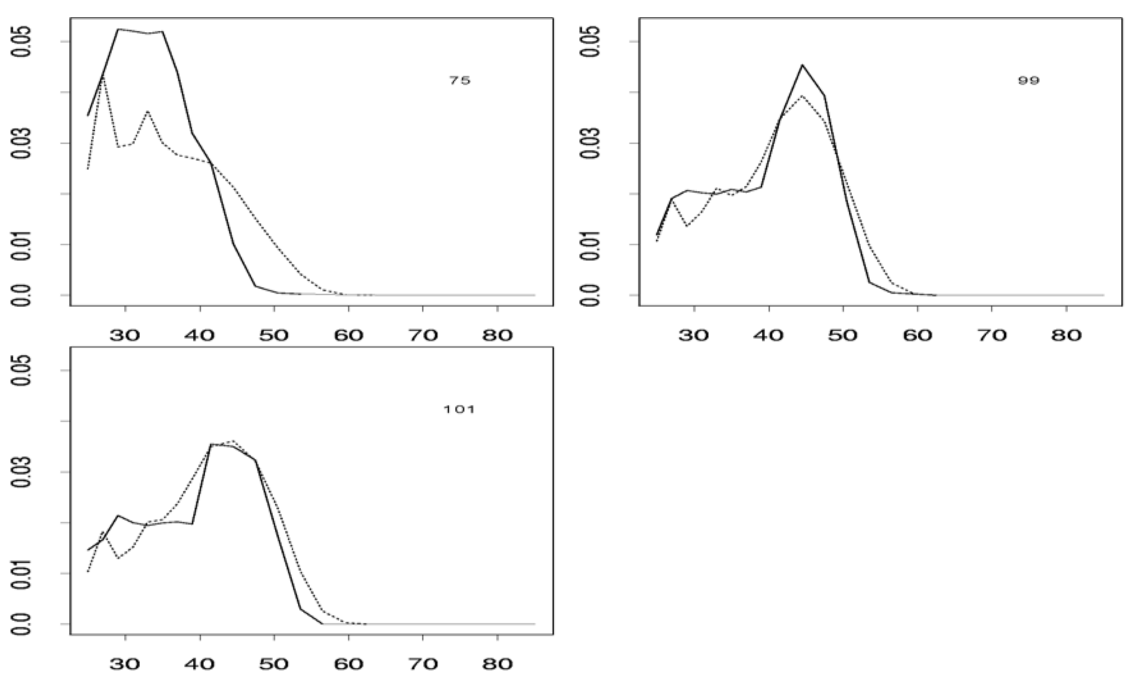

Figure 4.8. Fit to the male survey length data. Dotted line is predicted. 101 is year 2001.

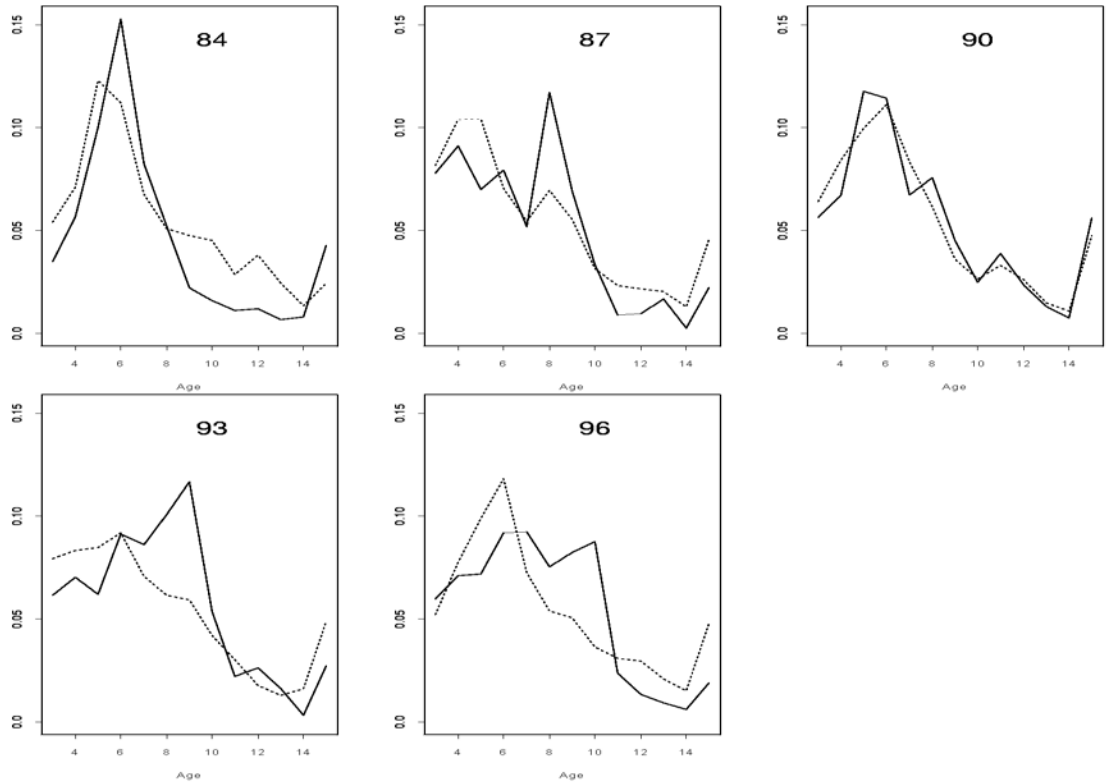

Figure 4.9. Fit to the female survey age data. The last age group is 15+. Dotted line is predicted.

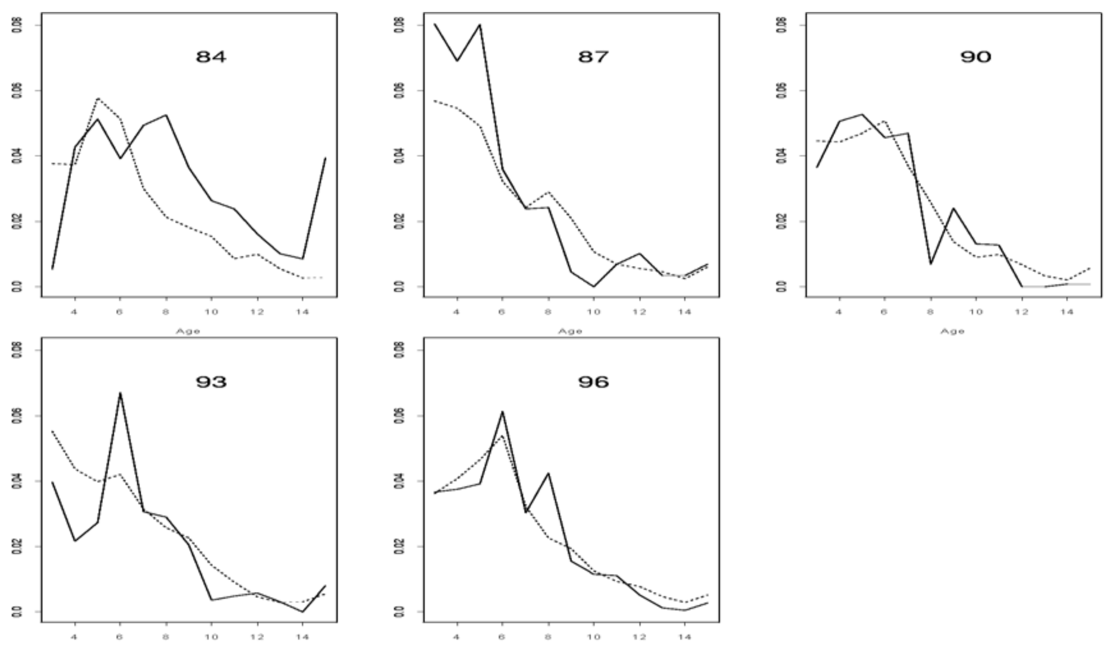

Figure 4.10. Fit to the male survey age data. The last age group is 15+. Dotted line is predicted.

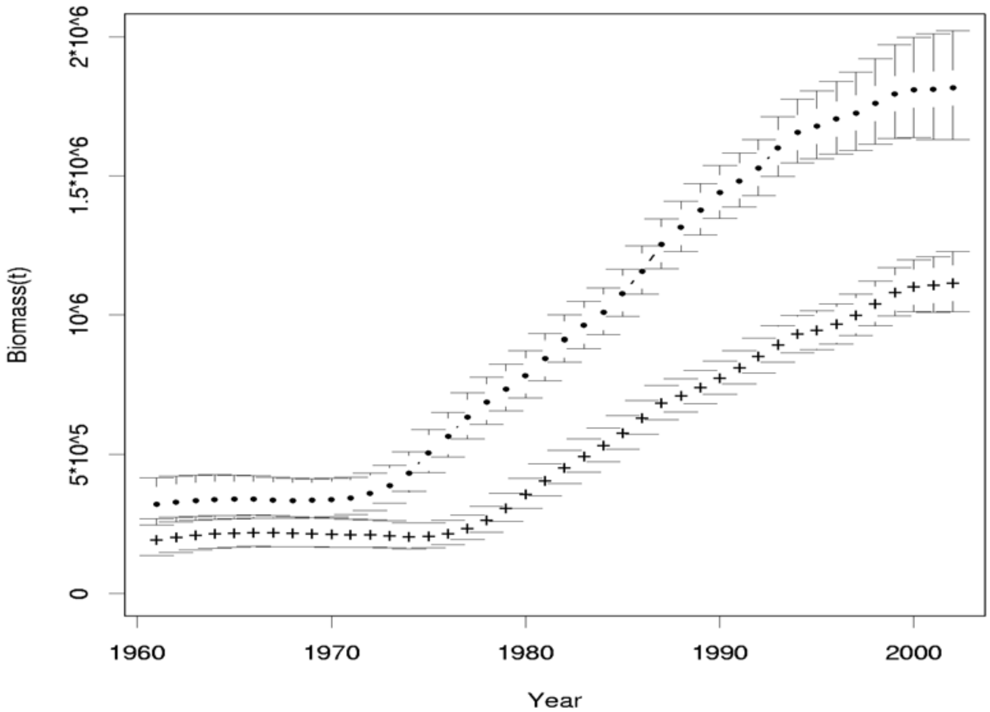

Figure 4.11. Age 3+ biomass (solid line) and female spawning biomass (line with +) from 1984 to 2001. The approximate lognormal 95% confidence intervals shown underestimate the uncertainty because variance in natural mortality and survey Q as well as other fixed parameters are not accounted for.

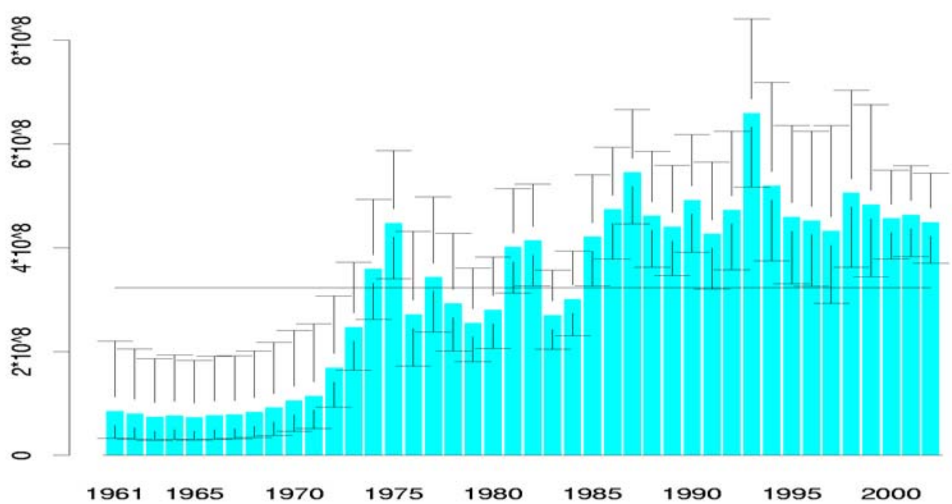

Figure 4.12. Age 3 estimated recruitments (male plus female) in numbers from 1961 to 2002, with approximate 95% confidence intervals. Horizontal line is average recruitment.

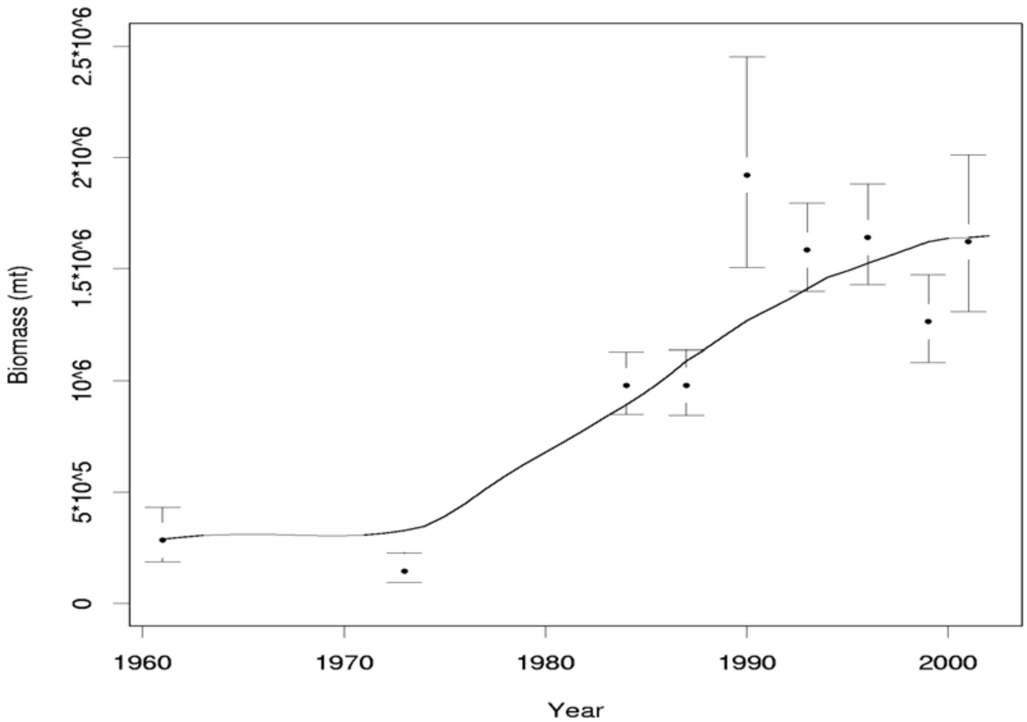

Figure 4.13. Fit to survey biomass estimates with approximate 95% log-normal confidence intervals for the observed survey biomass estimates 1961 to 2001.

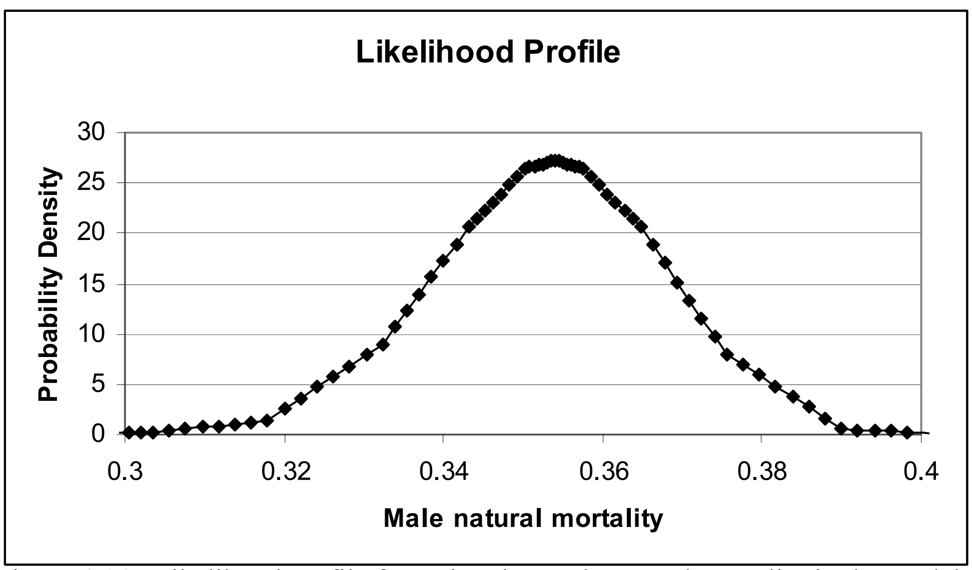

Figure 4.14. Likelihood profile for estimating male natural mortality in the model. 95% confidence interval is 0.322 to 0.384. The mean and mode both equal 0.354.

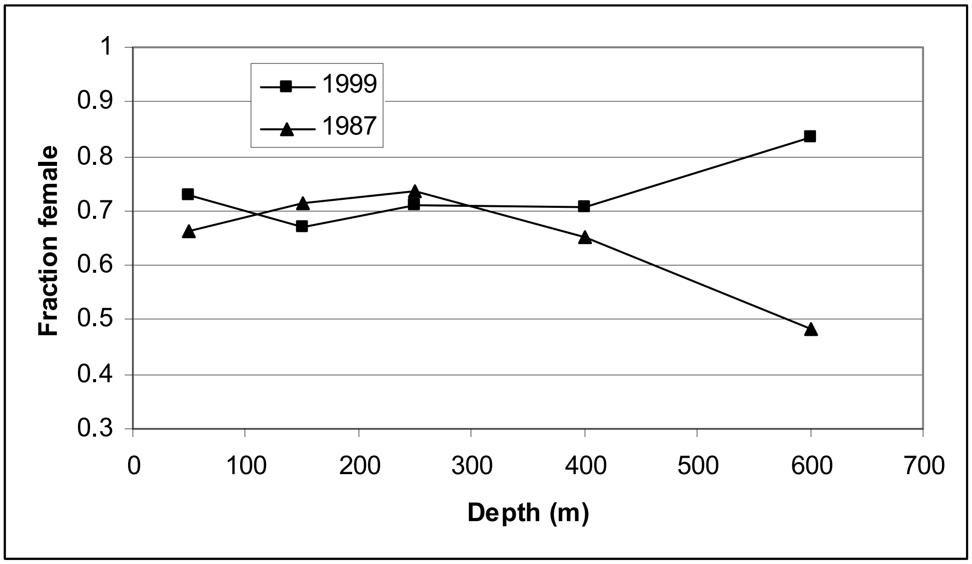

Figure 4.15. Fraction female by depth (midpoint of the depth strata) for the 1999 and 1987 survey data which covered depths to 700 meters.

Appendix A.

Table A.1. Model equations describing the populations dynamics.

$N_{t,1} = R_t = R_0 e^{\tau_t}$	$\tau_t \sim N(0, \sigma_R^2)$		Recruitment
$C_{t,a} = \frac{F_{t,a}}{Z_{t,a}}(1 - e^{-Z_{t,a}}) N_{t,a}$		$1 \le t \le T$ $1 \le a \le A$	Catch
$N_{t+1,a+1} = N_{t,a} e^{-Z_{t,a}}$		$1 < t \le T$ $1 \le a < A$	Numbers at age
$FSB_t = \sum_{a=1}^{A} w_a \phi_a N_{t,a}$			Female spawning biomass
$N_{t+1,A} = N_{t,A-1} e^{-Z_{t,A-1}} + N_{t,A} e^{-Z_{t,A}}$		$1 < t \le T$	Numbers in "plus" group
$Z_{t,a} = F_{t,a} + M$			Total Mortality
$C_t = \sum_{a=1}^{A} C_{t,a}$			Total Catch in numbers
$p_{t,a} = C_{t,a} / C$			proportion at age in the catch
$Y_t = \sum_{a=1}^{A} w_{t,a} C_{t,a}$			Yield
$F_{t,a} = s_{t,a} E_t e^{\varepsilon_t}$	$\varepsilon_t \sim N(0, \sigma_R^2)$		Fishing mortality
S_a for a = 3 to 13			selectivity – smooth monotonically increasing function for fishery
S_a for a = 3 to 13			selectivity –ascending logistic for survey
$SB_t = Q \sum_{a=1}^{A} w_a s_{t,a}^s N_{t,a}$			survey biomass, Q = 1.

Table A.2. Likelihood components.

$\sum_{t=1}^{T}\left[\log(C_{t,obs})-\log(C_{t,pred})\right]^2$	Catch using a lognormal distribution.
$\sum_{t=1}^{T}\sum_{a=1}^{A} nsamp_t * p_{obs,t,a}\log(p_{pred,t,a})$ - offset	age and length compositions using a multinomial distribution. Nsamp is the observed sample size. Offset is a constant term based on the multinomial distribution.
offset = $\sum_{t=1}^{T}\sum_{a=1}^{A} nsamp_t * p_{obs,t,a}\log(p_{obs,t,a})$	the offset constant is calculated from the observed proportions and the sample sizes.
$\sum_{t=1}^{ts}\left[\frac{\log\left[\frac{SB_{obs,t}}{SB_{pred,t}}\right]}{sqrt(2)*s.d.(\log(SB_{obs,t}))}\right]^2$	survey biomass using a lognormal distribution, ts is the number of years of surveys.
$\sum_{t=1}^{T}(\tau_t)^2$	Recruitment, where $\tau_t \sim N(0,\sigma_R^2)$
$\sum_{a=3}^{15}(diff(diff(s_a)))^2$	Smooth selectivities. The sum of the squared second differences.

Table A.3. List of variables and their definitions used in the model.

Variable	Definition
T	number of years in the model(t=1 is 1961 and t=T is 2002
A	number of age classes (A =13, corresponding to ages 3(a=1) to 15+)
w_a	mean body weight(kg) of fish in age group a.
ϕ_a	proportion mature at age a
R_t	age 3(a=1) recruitment in year t
R_0	geometric mean value of age 3 recruitment
τ_t	recruitment deviation in year t
$N_{t,a}$	number of fish age a in year t
$C_{t,a}$	catch number of age group a in year t
$p_{t,a}$	proportion of the total catch in year t that is in age group a
C_t	Total catch in year t
Y_t	total yield(tons) in year t
$F_{t,a}$	instantaneous fishing mortality rate for age group a in year t
M	Instantananeous natural mortality rate
E_t	average fishing mortality in year t
ε_t	deviations in fishing mortality rate in year t
$Z_{t,a}$	Instantantaneous total mortality for age group a in year t
s_a	selectivity for age group a

Table A.4. Estimated parameters for the Admodel builder model. There were 124 total parameters estimated in the model.

Parameter	Description
$\log(R_0)$	log of the geometric mean value of age 3 recruitment
τ_t $1961 \le t \le 2002$, plus 14 parameters for the initial age composition equals 56.	Recruitment deviation in year t
$\log(f_0)$	log of the geometric mean value of fishing mortality
ε_t $1961 \le t \le 2002$, 42 parameters	deviations in fishing mortality rate in year t
s_a for ages 3 to 13, 22 parameters	selectivity parameters for the fishery for males and females.
Slope and 50% for logistic function, 2 parameters	selectivity parameters for the survey for males and females.

Table A.5. Fixed parameters in the Admodel builder model.

Parameter	Description
M = 0.2 females , M=0.35 males	Natural mortality
Q = 1.0	Survey catchability
L_{inf} , L_{age2} , k , cv of length at age 2 and age 20 for males and females	von Bertalanffy Growth parameters estimated from the 1984-1996 survey length and age data.